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Analysis of Power Output Impact on PV rooftop system under Different Installation Positions by PSCAD

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Abstract

This paper aims to simulate power output impact of different installation positions of PV rooftop system. The methods are to investigate the influence parameters which are tilt angle of PV array, roof azimuth, and irradiance losses. For investigation, the connections of PV array in various forms are proposed. In addition, the results are analyzed to describe the relationship of a recommended maximum power point tracking. In this paper, the using PSCAD is validated for simulation of maximum power point on various PV arrays. The results demonstrate that the methods have a high accuracy in the simulation and allow the design of an appropriate location for the installation of PV rooftop system.

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Keywords: Photovoltaic rooftop; I-V and P-V Curve; tilt angle of Photovoltaic; PSCAD.

1. INTRODUCTION

Nowadays, electricity is very important for living and electrical energy consumption is increasing. Renewable energy which emissions CO2 less is a clean energy source and environment friendly. One of the most rising renewable energy sources is the photovoltaic energy. However, the price of this energy is at this high and

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photovoltaic system efficiency is not satisfactory. Therefore, the suitable position installation of photovoltaic is necessary. An important determinant for a PV rooftop system is not only useful for the solar cell with high efficiency but also an effective system with multipurpose for rooftops. The PV rooftop systems have a major problem with the position of installation because the roof angle could not be designed to fit with the suitable PV angle. Therefore; the energy yield of PV rooftop is very dependent on the roof angle. In 1988, Graham V. Stated that a lot of the methods for the daily generated solar irradiation sequences [1] and Pereira M. and Conde J. used the Aguiar's method. This method is the most widely used today [2]. In 1971, electrical output of shadowed solar array was calculated by Rauschenbach and he reported model of irradiation loss by partial shading [3]. The simulations for shaded solar cell with computer becoming possible more recently had been done in 1988 and 1996 by several researchers [4, 5, and 6]. With good computers today, calculations of the impact of various shading situations on PV array have been published many times [7, 8, 9, and 10]. In all previous studies, possibility of partially shading on PV array had been studied, also another condition with different installation position in the case has not been investigated. This paper studies an expansion of PSCAD to analyze the output power impact on PV rooftop system under different installation positions.

2. THEORETICAL APPROACH FOR SIMULATION

2.1. A calculation of solar irradiance on PV array surface

The solar intensity on a surface of PV array is very important to engineers design. In 2011, Antonio Luque and Steven Hegedus reported in Handbook of Photovoltaic Science and Engineering and described the easily calculation of solar irradiance on the PV array. The researchers can calculate solar irradiance on the PV array through the following this steps [11].

The solar declination angle, δ is shown in (1) with a particular geographic latitude φ and the counted day from the starting of the year, d_n. The angle 23.45^o is a constant angle with the ecliptic flat. In Fig.1, the earth moves around the sun, with the slanted polar axis; and Fig.2 adds some appoint for a speciality day and a speciality geographic latitude φ.

$$\delta = 23.45^o \sin\left[\frac{360(d_n + 284)}{365}\right] \tag{1}$$

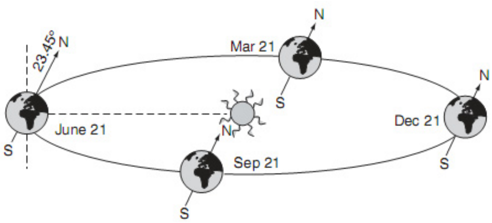

Fig.1 The moving of the Earth around the sun [11]

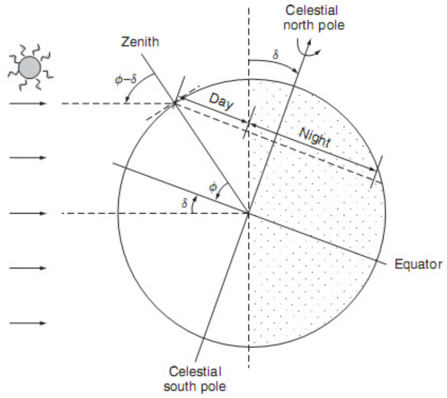

Fig.2. Relative of Earth and Sun positions at noon of a negative declination [11]

The solar zenith angle θ_{ZS} can be calculated with the solar declination angle, δ. That show in Fig.3. Between the sun and the meridians of the location is the solar azimuth ψ_S. The element of the zenith angle is called the solar altitude, γ_S. At all given, the researcher calculated the angular integrates of the sun with follow to a point of geographic latitude ϕ (north positive, south negative) from the equations:

$$\cos\theta_{ZS} = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega = \sin\gamma_S \tag{2}$$

and

$$\cos\psi_S = \frac{(\sin\gamma_S\sin\phi - \sin\delta)}{\cos\gamma_S\cos\phi}\left[sign(\phi)\right] \tag{3}$$

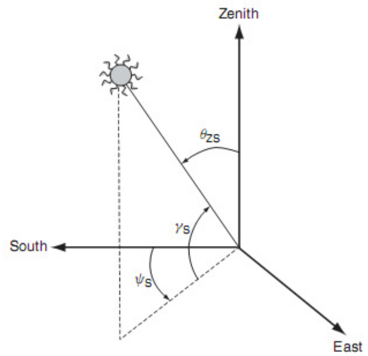

Fig.3. Position of the sun relative to a fixed point on the Earth defining the two critical angles ψ_S (azimuth) and θ_{ZS} (solar zenith). The complement of the last, γ_S (altitude)

The engineering design used solar time, ω with the local official time TO, the local longitude LL, the archives longitude of the local time zone (positive forwards the west and negative forwards the east of the Greenwich Meridian) LH and the setting time of the local timezone AO to calculate The angle of solar incidence between the sun's irradiations and the normal to the surface, θ_s. And solar time equation is shown in (4)

$$\omega = 15\times(TO - AO - 12) - (LL - LH) \tag{4}$$

The researcher can calculate the angle of solar incidence between the sun's irradiations and the normal to the surface with slope β (the angle formed with the horizontal) and the azimuth α of the normal to the surface from (5) and all detail are shown in Fig.4.

$$\cos\theta_S = \sin\delta\sin\phi\cos\beta - [sign(\phi)]\sin\delta\cos\phi\sin\beta\cos\alpha + \cos\delta\cos\phi\cos\beta\cos\omega + [sign(\phi)]\cos\delta\sin\phi\sin\beta\cos\alpha\cos\omega + \cos\delta\sin\alpha\sin\omega\sin\beta \quad (5)$$

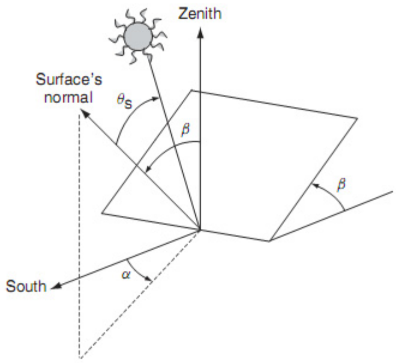

Fig.4 Collector position (slope β and azimuth α) and sun's irradiations incidence angle θ_S [11]

And the easily calculation of solar irradiance on the PV array can be calculated with this equation

$$G(\theta_S) = G_{ref}\cos\theta_S \quad (6)$$

The reference solar irradiation is $G_{ref} = 1000\ W/m^2$ under Standard Reference Condition (SRC)

2.2. The Basic of the relationship between current–voltage for a photovoltaic module

In 2004, Masters, G.M. stated that renewable and efficient electric power systems and described "an equivalent circuit composed of a current source, an anti-parallel diode, a series resistance and a shunt resistance represented a solar cell traditionally [12]." As shown in Fig. 5.

In 2012, the output current I_A and output voltage V_A of a PV module with N_S cells in series and N_P strings in parallel in a cell to module to array detailed model for PV panels is calculated from the following equation (6, 7, and 8) by several researchers [13].

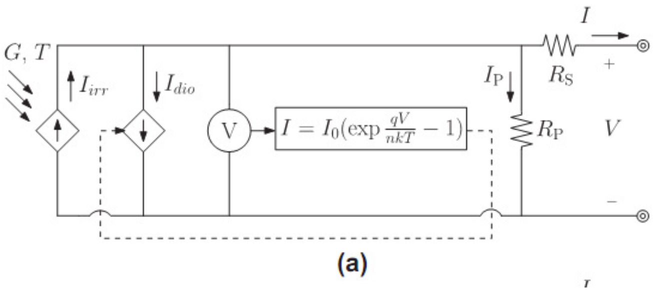

Fig.5 Modified equivalent circuit for (a) a single solar cell

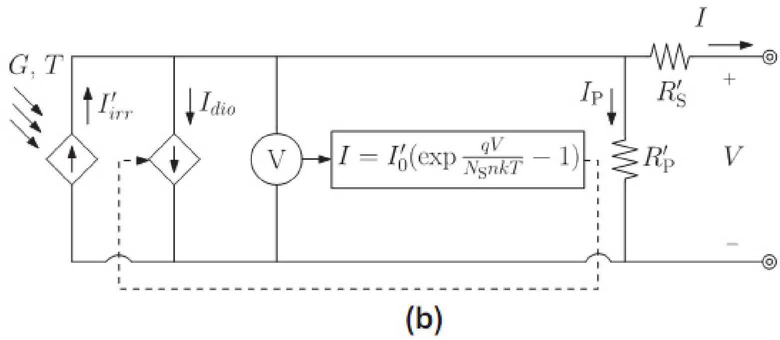

Fig.5 (Cont.) Modified equivalent circuit for (b) an array of an arbitrary size. [13]

$$I_A = N_P I_{irr} - N_P I_0 \left[\exp\left(\frac{q\left(V_A + I_A \frac{N_S}{N_P} R_S\right)}{N_S nkT} - 1 \right) \right] - \frac{V_A + I_A \frac{N_S}{N_P} R_S}{\frac{N_S}{N_P} R_P} \tag{7}$$

Boltzmann constant $k = 1.3806503 \times 10^{-23}\ J/K$, the ideal constant factor of the diode n, the temperature of the cell T, and the saturated diode current I_0 are parameter in equation (7) and can be rewritten as,

$$I = I'_{irr} - I'_0 \left[\exp\left(\frac{q\left(V + IR'_S\right)}{N_S nkT} - 1 \right) \right] - \frac{V + IR'_S}{R'_P} \tag{8}$$

2.3. Model parameters

2.3.1 Photo Current I_{irr}

In 2006, Duffie, J.A., Beckman, W.A. stated that Solar Engineering of Thermal Processes and described "the photo current (I_{irr}) depends on the solar irradiance G and cell temperature T" and is given by [14]

$$I_{irr} = I_{irr,ref} \left(\frac{G}{G_{ref}}\right)[1 + \alpha'_T (T - T_{ref})] \tag{9}$$

The photo current $I_{irr,ref}$, the relative temperature coefficient of the short-circuit current α'_T, the reference solar irradiation G_{ref} = 1000 W/m^2 and the reference cell temperature T_{ref} = 298 K or T_{ref} =25^{o}C are parameter for calculation in (9).

2.3.2 Diode saturation current I_0

Diode saturation current I_0 is primarily dependent on the temperature of the cell [14]:

$$I_0 = I_{0,ref} \left[\frac{T}{T_{ref}}\right]^3 \exp\left[\frac{E_{g,ref}}{kT_{ref}} - \frac{E_g}{kT}\right] \tag{10}$$

The saturated diode current at SRC $I_{0,ref}$, and the bandgap energy E_g [eV] are parameter for calculation in (10). Pierret, R.F., 1996 defined the value of E_g for silicon in Semiconductor Device Fundamentals [15]

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{T + \beta} \tag{11}$$

where

$E_g(0) = 1.170\ eV,\ \alpha = 4.730 \times 10^{-4}\ eV/K,\ \beta = 636\,K$

3. SIMULATION OF SYSTEM

In this paper, a simulation of electric generation for Photovoltaic array is done by PSCAD. SMA SOLAR ACADEMY shown location affects radiation on PV array in Fig.6

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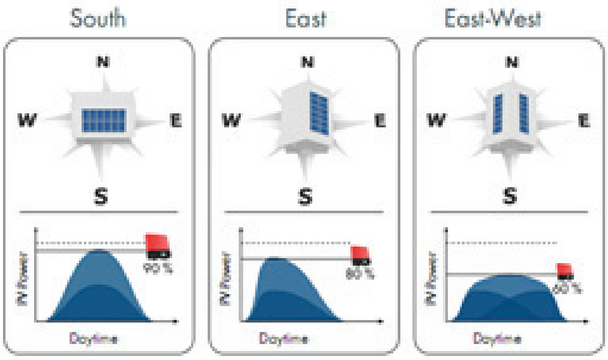

Fig.6 A plant's location influences power ratio. [16]

The PSCAD model consists of PV array model, transmission line parameter, and variable voltage source, as show in Fig. 7.

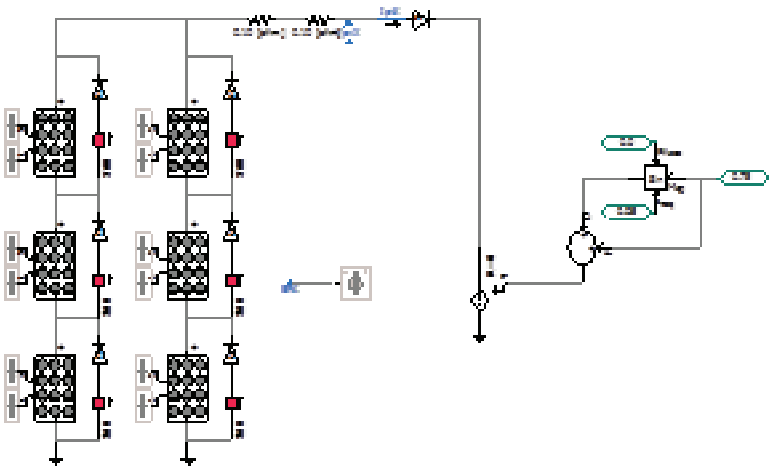

Fig.7 Model for simulation.

The researcher used the standard parameters which are shown in Table 1 to define the PV module in PSCAD.

Table 1. The standard parameters of the PV Module

PV array parameters	PV array name	PV array 1
	No. of modules connected in series /array	8
	No. of module strings in parallel / array	22
	No. of cells connected in series / module	60
	No. of cell strings in parallel / module	1
	Reference Irradiation (W/m^2)	1000
	Reference cell temperature (^oC)	25
PV cell parameters	Effective area / cell (m^2)	0.01
	Series resistance / cell (Ω)	0.02
	Shunt resistance / cell (Ω)	100
	Diode ideality factor	1.5
	Band gap energy (eV)	1.103
	Saturation current at reference conditions / cell (A)	$1x10^{-9}$
	Short circuit current at reference. conditions / cell (A)	2.5
	Temperature Coefficient of photo current (A/K)	0.001

An example of construction of rooftop is shown in Fig. 8 which has different angle for PV installation.

Fig. 8 The rooftop which was used to install the PV system

4. RESULTS OF SIMULATION

Without effect of tilted angle and no irradiance loss on the output of the PV array were simulated. The I-V and P-V characteristic of the PV array for radiation level of 1000 W/m^2 and temperature 35^oC in each PV array is show in Fig. 9.

Without effect of tilted angle but PV array have cloud motion effect and radiation level drop 20%, 40% and 60% on the output of the PV array were simulated. The output current is decrease. The I-V and P-V characteristic of the PV array are show in Fig.10-12.

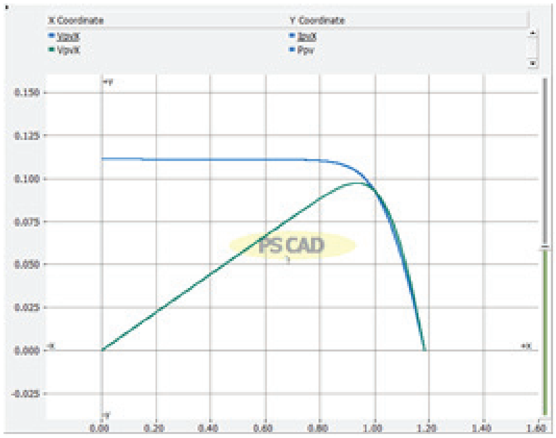

Fig. 9 The I-V and P-V curve with one PV tilted angle

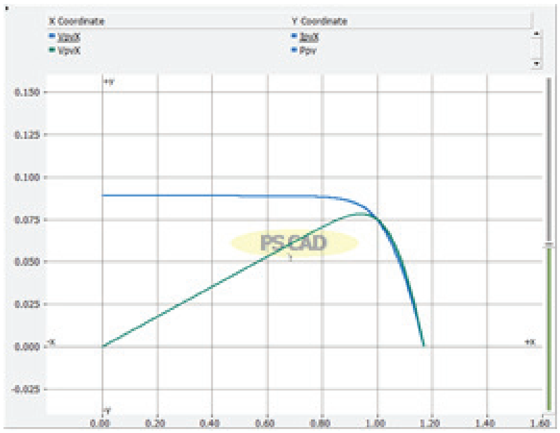

Fig. 10 The I-V and P-V curve with one PV tilted angle and radiation level of 800 W/m^2

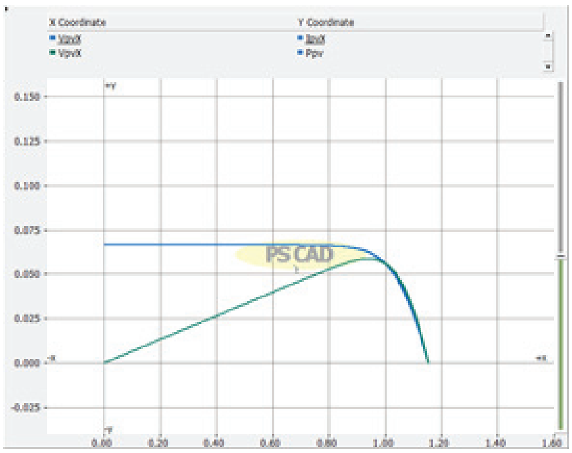

Fig. 11 The I-V and P-V curve with one PV tilted angle and radiation level of 600 W/m^2

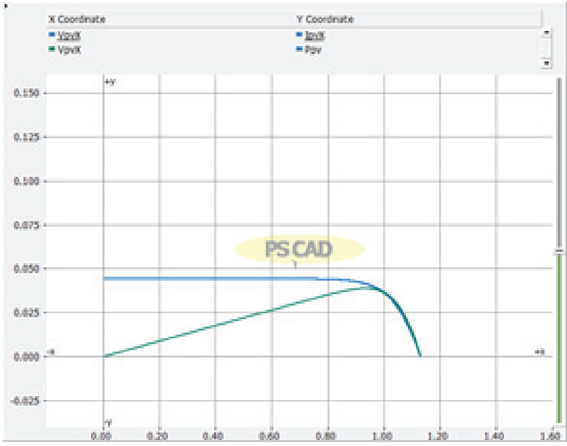

Fig. 12 The I-V and P-V curve with one PV tilted angle and radiation level of 400 W/m^2

If some parts of PV array are irradiance losses with effect of tilted angle and sun movent, the output power from PV array will decrease significantly. Fig. 13 is the graph of the result of I-V and P-V characteristic with 3 parts of PV array have radiation level of 800 W/m^2 and temperature 35^{o}C. One part of PV array has radiation level of 400 W/m^2 and temperature 35^{o}C and 2 parts of PV array has radiation level of 600 W/m^2 and temperature 35^{o}C. In this case, the output of the PV array has 2 maximum power points.

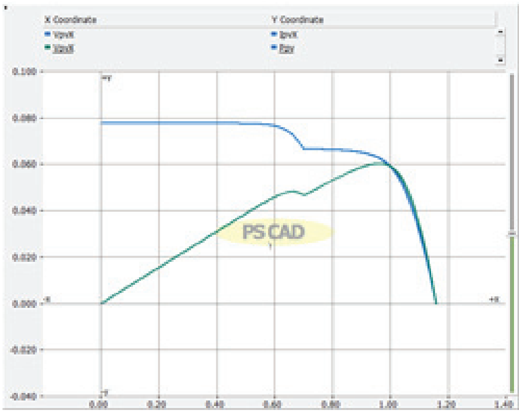

Fig.13 The I-V and P-V characteristics with different PV tilted angle and sun movement

With effect of tilted angle, cloud motion effect and sun movement, radiation level on PV arrays are 800 W/m^2, 650 W/m^2, 600 W/m^2, 400 W/m^2, 500 W/m^2, and 300 W/m^2 with constant temperature 35^{o}C. In this case, the result of output from the PV array has 3 maximum power points. The I-V and P-V characteristic of this array are show in Fig.14.

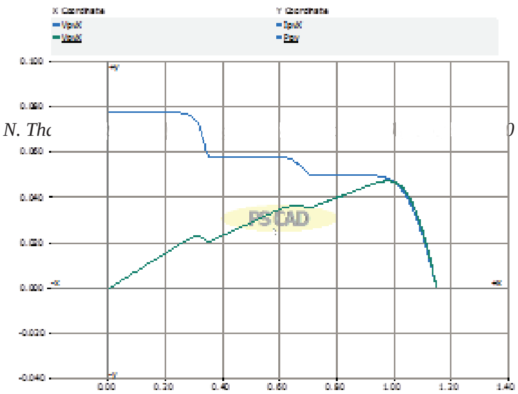

Fig.14 The I-V and P-V characteristics with different PV tilted angle, cloud effect and sun movement

From Fig. 15 it is the comparision of different I-V curve. The top of curve shows the good power output from PV array without effect of tilted angle and no irradiance loss. Under influence of tilt angle, rooftop azimuth and sun movement, the output power from another curve of PV array will decrease. If the controller operating of maximum power point tracking range is selected maximum power point too narrow, the lower maximum power point might be outside the range or in case the controller will operate always with the upper maximum power point maximum power point resulting in reduced energy yield.

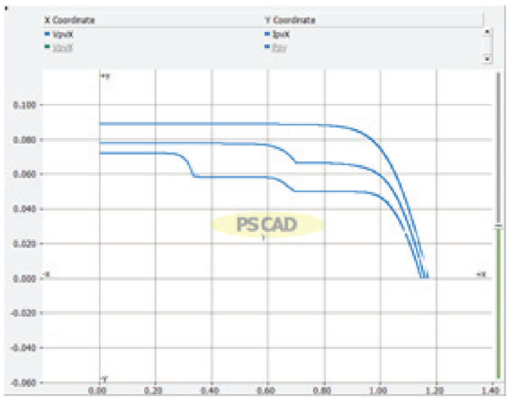

Fig.15 The comparision of different I-V curve.

5. CONCLUSION

This simulation takes operating conditions of PV array such as time varying sunlight intensity, where each PV module is under influence of tilt angle, rooftop azimuth and sun movement. The results of this paper show that PV angle conditions determine the efficiency with partial irradiance losses by using central inverter because central inverter can detect only one maximum power point in I-V curve.

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